Foraminiferal biostratigraphy and palaeoenvironments of the Miocene-Pliocene Carboneras-Nijar Basin (SE Spain)

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Five successive, distinct, microfossil assemblages, primarily characterized by their benthic foraminiferal contents, have been recognized in the Mio-Pliocene of the Carboneras-Nijar Basin (SE Spain). The assemblages record a number of fundamental changes in the environment of the area, which have been dated by means of planktic foraminifer biostratigraphy.

In the earliest Messinian the central part of the basin was several hundreds of metres deep and had relatively open marine conditions, which were followed by oxygendeficiency, accompanied by slightly deviating salinities and some reduction in waterdepth. Subsequent deposition of Messinian evaporites was interrupted by sparse more open marine sedimentation.

During the late Messinian brackish conditions became dominant and the basin filled with delta-plain sediments. The early Pliocene saw a sudden return to open marine, outer neritic conditions, which shoaled to an inner neritic environment in the middle Pliocene.

Since the Carboneras-Nijar Basin was close to the connection between the Mediterranean Sea and the Atlantic Ocean, its history shows that Atlantic inflow became more and more severed in the course of the Messinian and was, either completely or virtually, obstructed in its latest part.

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Introduction

Foraminiferal biostratigraphy and palaeoecology of the Miocene-Pliocene of the southern Almería province (SE Spain; Fig. 1) have previously been discussed in detail for part of the section (Montenat et al., 1976; Civis et al., 1979; Troelstra et al., 1980; Poore & Stone, 1981) or as part of studies with a wider framework (Völk, 1967; Iaccarino et al., 1975; Perconig, 1976; Geerlings & van de Poel, 1979; Dronkert et al., 1979; Ott d'Estevou, 1980; de la Chapelle, 1987; van de Poel, 1991).

Different opinions remain, in the first place as to the question whether Messinian evaporite deposition was interrupted and followed by important marine incursions in this area (Perconig, 1976; Montenat et al., 1976, 1980; Ott d'Estevou, 1980; Poore & Stone, 1981; Müller & Hsü, 1987; de la Chapelle, 1987) or whether it remained isolated during middle and late Messinian time (Iaccarino et al., 1975; Geerlings & van de Poel, 1979; Dronkert et al., 1979; Roep & van Harten, 1979; Troelstra et al., 1980; Geerlings et al., 1980a, b; de Deckker et al., 1988).

On a more regional scale, opinions converge on the importance of upwelling of nutrient-rich deeper water during deposition of the sediments directly underlying the Western Mediterranean Messinian evaporites (Bizon et al., 1979; McKenzie et al., 1980; Gersonde, 1980; van der Zwaan, 1982; Müller & Schrader, 1989; Hodell et al., 1989; Benson et al., 1991). No agreement has been reached on whether the Mediterranean shoaled during the early Messinian, nor on whether salinities were still normal or already elevated at this time (Sturani, 1978; Cita et al., 1978; Colalongo et al., 1979; Orszag Sperber et al., 1980; Troelstra et al., 1980; Ott d'Estevou, 1980; Poore & Stone, 1981; van der Zwaan, 1982).

Since the Almería region is situated at the Mediterranean end of the Atlantic/ Mediterranean gateways (Fig. 1), its fossil record may provide answers to those questions (Müller & Hsü, 1987; Benson et al., 1991).

This paper describes the Miocene-Pliocene microfaunal development, and discusses its palaeoenvironmental and palaeogeographical significance. The studied sections are located in the central part of the Carboneras-Nijar Basin, which is a Neogene-Quaternary depression near Cabo de Gata (Figs. 1, 2). Details on lithology and stratigraphy of the sections were given in van de Poel (1991).

METHODS

A (composite) section in the eastern-central part of the Carboneras-Nijar basin has been sampled in detail for micropalaeontological analysis (Section 3 of Fig. 2, Encl. 1). Two other sections, one at Gafares (Section 2) and one near Los Feos (Section 1) were studied to check whether the observed trends are of more than local importance,





and to get more information on the relation between microfossil content and lithology. The sampled interval (Encl. 1) comprises the Abad Marl of the Turre Formation, the Messinian evaporite-bearing Yesares Formation, the alternating coarse clastic and pelitic sediments of the Feos Formation, and the calcareous silts and sands of the Cuevas and Molata Formations, which are rich in marine macrofossil remains (van de Poel, 1991).

Samples have been washed over a 63 μ m sieve and have been examined to determine five semi-quantitative frequency classes of microfossil taxa and some non-microfossil constituents (Enclosures 2-4); details on the taxa are given in the Appendix. Ranges of characteristic species or genera are presented in Fig. 3.

The relative frequency of major and some minor chemical constituents in a set of samples from the Abad Marl has been determined by atomic absorption spectrometry (Fig. 4).

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D. van Harten, W. Meijboom and Th. G. van Kempen (GMCA) have identified ostracod species and sponge material. Chemical analysis have been performed on AAS by Marjan Reith of the Sedimentology Laboratory of the University of Utrecht, whereas SEM photographs would not have been taken without the indispensible help of Saskia Kars (GMCA). S. Nederbracht is thanked for advice in arranging the plates. Jan E. van Hinte (GMCA) reviewed versions of the manuscript. He, and Y. Gourinard of the University Paul Sabatier (Toulouse), are acknowledged for supporting this study.

Biostratigraphic descriptions

ASSEMBLAGES

The distribution of microfossils (Enclosures 2-4; Fig. 3) allows for the recognition of five distinct assemblages (A-E). The subdivision is primarily based on changes in benthic foraminiferal content, but also takes the relative frequency and composition of planktic foraminifer fauna and remaining fossil constituents into account. It is based on Section 3 (Encl. 2), but can also be recognized in the other sections (Enclosures 3, 4).

Fig. 2A. Geological map of the northern part of the Carboneras-Nijar Basin with location of measured composite Sections 1-3.

B. Setting of the northern Carboneras-Nijar Basin in the southern Almería Province. I = Carboneras-Nijar Basin, II = Sorbas Basin; III = Agua Amarga Basin.



TURRE FORMATION YESARES FI					M	FEOS FM			CUEVAS MOLATA		LITHOSTRATIGRA	PHY					
C SI	G. conomiozea T. qui		3. conomiozea T. quinqueloba				Reworked Interz.			G.marg. G.punct.		pF Zone	모궁	ST			
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					-	_	-	·	-					 	G. menardii G. conomiozea G. margaritae G. crassaformis G. scitula G. suterae G. puncticulata N. acostaensis S N. acostaensis D T. quinqueloba	PLANKTIC FORAMS	
-				-		-									fine agglutinants <i>Textularia</i> spp. fragile nodosariids robust nodosariids		
-				- 	-		-	 -	-		-				Planulina ariminensis small deep water taxa Cassidulina spp. C. pseudoungerianus Cibicidaidaa ditemplai		MIC
-				- -		-					-				A. colligerus small epiphytes Cibicides lobatulus		ROFOS
												-			Neoeponides sp. Siphonina sp. Uvigerina striatissima U. longistriata	BENT	SILS
-			+	-							-	-			Bulimina costata Bolivina arta Bolivina alata	HIC FOI	
				 -	-			_					 	 	Uvigerina perigrina s.l. Bulimina minima Bulimina aculeata	PAMS	
											-	 			nectung,/Hopkins. sp. Bulimina elongata Bolivina dilatata Bolivina spathulata		
					-										Elph. aculeatum Elphidium sp. A Elphidium crispum Ammonia beccarii Ammonia teoida		
	-				_									 -	Cyprideis sp. Loxoconcha sp. pink molluscs Chara sp. Microcodium sp.	OTHER	

Fig. 3. Ranges of foraminiferal taxa with chronostratigraphic and environmental importance.

Assemblage A (samples Po 142-PM 183, Pl. 1).

Assemblage A is characterized by high frequencies of benthic foraminifera from both a diverse group (finely agglutinated species, fragile nodosariids, *Lenticulina* spp., *Planulina ariminensis*, 'small deep water taxa', *Cibicidoides pseudoungerianus*), and a first, distinct group of buliminids (*Uvigerina peregrina*, *Bulimina costata*, *B. aculeata* f. *minima*, *Bolivina arta*, *B. dilatata*, and *B. subreticulata*) (Enclosures 2, 4; Fig. 3; Pl. 1). A diverse planktic foraminifer fauna (commonly about 70% of the foraminifera) and the presence of glauconite further characterize Assemblage A. This unit can be subdivided in three parts.

Subassemblage A1 covers the lowermost sample (Po 142), in which *Cassi*dulina, *Cibicidoides* and epiphytes dominate the benthic foraminiferal assemblage together with *Elphidium crispum*. In contrast to the relatively low foraminiferal number, it has a high content in bryozoan and echinoid remains and sand-sized terrigenous debris.

An increase in frequency and diversity of the benthic foraminifera marks the base of Subassemblage A2 (samples Po 132-PM 164), which is characterized by the presence of *Uvigerina striatissima*, finely agglutinated taxa and *Anomalinoides colligerus*.

Diversity decreases in the upper Subassemblage A3 (samples PM 167-183), where *Cibicidoides pseudoungerianus* is dominant and *Bulimina costata* and *Uvigerina peregrina* reach high numbers, whereas characteristic elements of Assemblage B make their first appearance. A similar *C. pseudoungerianus* Assemblage was found in the middle part of the Abad Marl of the adjacent Sorbas Basin (Troelstra et al., 1980).

Assemblage B (samples PM 185-220; Pl. 2).

Assemblage B is first characterized by the consistent domination of a particular group of buliminaceans (Bolivina spathulata, accompanied by B. dentellata, Bulimina elongata, Globobulimina pyrula, Rectuvigerina cylindrica variants, and Hopkinsina bononiensis). Additional shallow-water taxa (Bolivina plicatella, Cancris auriculus, Valvulineria bradyana, small 'epiphytes', Ammonia and Elphidium spp., Florilus boueanum, occasional miliolids) are often found (Enclosures 2-4; Fig. 3). The planktic foraminifer assemblage similarly shows a low diversity with a tendency for different (groups of) taxa (G. bulloides s.l./Globigerinella siphoniphera, Orbulina/Globigerinoides spp., Turborotalita quinqueloba) to dominate in successive samples.

Small species are abundant in the low-diverse, but rich and well-preserved, foraminiferal faunas. Besides, frequent fragile bryozoan remains, sponge spicules, fish scales and teeth, and, more scattered, diatom and thin bivalve remains, are characteristic for this assemblage. It coincides with the upper, laminated part of the Abad Marl which is rich in manganese and iron hydroxides and fine-crystalline gypsum, and has a relatively high carbonate content (Enclosures 1-4; Fig. 4; van de Poel, 1991).

The lower Subassemblage B1 (samples PM 185-194) is characterized by a high frequency of *Cassidulina laevigata* and, more scattered, *Cibicidoides pseudoungerianus*, epiphytes, and globorotaliid and neogloboquadrinid planktic foraminifers.

Globigerina bulloides s.l. can reach high frequencies in this interval. Subassemblage B 2 (samples PM 197-PK 31) has consistently low foraminiferal diversity and strong fluctuations in P/B ratio.

An abrupt reduction in calcareous fauna determines the base of the upper Subassemblage B3 (sample PM 210-220), which is further characterized by the occurrence of foraminifera with a glossy porcelaneous coating, masking their ornamentation.

Assemblage C (samples PK 35-Ml 100, Pl. 2).

A final drop in diversity marks the lower boundary of Assemblage C, where the relatively larger benthic foraminiferal species of Assemblage B virtually disappear and the remaining assemblage consists of a few small taxa (Enclosures 2-4; Fig. 3). Elphidium sp. A is the most consistently present and, at certain levels, abundant. Besides, a few small bolivinids (especially *B. plicatella*) and epiphytes (Asterigerina planorbis and Rosalina globularis) are sometimes found. The planktic foraminifer (*T. quinqueloba*) and ostracod fauna's (Cyprideis sp.) are also impoverished. Manganese hydroxide, gypsum and fish remains are the dominant, and often only, constituents in the washed residues.

Subassemblage C1 (samples PK 35-PM 246) is characterized by an extreme paucity in microfossils, which partially may be ascribed to early dolomitization (van de Poel, 1991). Subassemblage C2 in Section 2 (samples Ml 150-151), contains common *Ammonia beccarii*, small epiphytes and a few miliolids. Subassemblage C3 (sam-

Plate 1

SEM micrographs of foraminifers characteristic for the Late Tortonian to earliest Messinian; all specimens \times 65, except for 13 a-c (\times 100).

Figs. 1-8. Benthic species characteristic for the latest Tortonian to earliest Messinian 'deep open marine' Assemblage A2.

Fig. 1. Eggerella bradyi (Cushman); sample PM 158, section 3.

Fig. 4. Elphidium fichtellianum (d'Orbigny); sample PK 49, section 2.

Fig. 5. Uvigerina striatissima Perconig; sample PM 164, section 3.

Fig. 7. Bolivina dilatata Reuss; sample PM 151, section 3.

Figs. 9-11. Benthic species characteristic for the early Messinian, marine, slightly oxygen-deficient Assemblage A3.

Fig. 9. Cibicidoides pseudoungerianus (Cushman); a: umbilical side; b: spiral side; sample PM 157, section 3.

Fig. 10. Bulimina costata d'Orbigny; sample PM 151, section 3.

Fig. 11. Uvigerina peregrina Cushman with costae on last chamber; sample PM 164, section 3.

Fig. 12. Uvigerina peregrina Cushman with pustulous (?and spinose) last chamber; a: short specimen; b: elongate specimen; sample PM 164, section 3.

Fig. 13. *Globorotalia conomiozea* Kennett, planktonic foraminifer characteristic for the early Messinian; a: umbilical side; b: side view; c: spiral side; sample PM 153, section 3.

Fig. 2. Melonis soldanii (d'Orbigny); sample PM 157, section 3.

Fig. 3. Pullenia quinqueloba (Reuss); sample PM 157, section 3.

Fig. 6. Bolivina arta MacFayden; sample PM 157, section 3.

Fig. 8. Bulimina aculeata d'Orbigny f. minima Tedeschi & Zanmatti; sample PM 158, section 3.



ples PM 252-PK 40A) represents a a more open-marine interval with common wellpreserved sponge spicules and fragile bryozoan remains. A sample from Section 2 (Po 143) contains *Uvigerina* sp. A and a relatively diverse small-sized planktic foraminifer fauna. Subassemblage C4 (sample PM 279-Ml 100) is again poor in microfossils but contains an interval with abundant fish remains (samples 289-40B, Section 3 and Ml 279, Section 2; de la Chapelle, 1987).

Assemblage D (samples PM 307-Po 151, Pl. 2).

The appearance of pink bivalve and gastropod remains, *Chara* and *Microcodium* sp. marks the base of Assemblage D, in which well-preserved ostracods of all mold sizes are the most common microfossils. *Ammonia tepida* is characteristic for the relatively rare autochthonous benthic foraminiferal assemblage.

Plate 2

SEM micrographs of foraminifers characteristic for the late early, middle and late Messinian Assemblages B, C and D; all specimens \times 65, except for 11 a-c and 12 a-b (\times 100).

Figs. 1-10. Benthic species characteristic for the late early Messinian, marine, low-oxygen Assemblage B.

Fig. 1a, b. Small Uvigerina sp. cf. U. peregrina Cushman with costae on last chamber, sample PM 201, section 3.

Fig. 2. Bulimina aculeata d'Orbigny; sample PK 61, section 2.

Fig. 3. Hanzawaia bouena (d'Orbigny); sample PM 173, section 3.

Fig. 4. Elphidium aculeatum (d'Orbigny); sample PK 201, Section 3.

Fig. 5. Rectuvigerina cylindrica (d'Orbigny) f. cylindrica (Thomas); sample PK 56, section 2.

Fig. 6. Rectuvigerina cylindrica (d'Orbigny) f. gaudryinoides (Lipparini); sample PK 111, section 1.

Fig. 7. Bulimina elongata d'Orbigny; sample PM 201, section 3.

Fig. 8. Hopkinsina bononiensis (Fornasini); sample PK 111, section 1.

Fig. 9. Bolivina spathulata (Williamson); sample PK 56, section 2.

Fig. 10. Bolivina dentellata Tavani; sample PM 201, section 3.

Figs. 11, 12. Characteristic planktic foraminifera of the early to middle Messinian, Assemblages B and C.

Fig. 11. *Turborotalita quinqueloba* (Natland); a: form with lip; b: most common form; c: atypical form, with coiling as in *Globigerina*; three specimens from sample PM 201, section 3.

Fig. 12. Dextral *Neogloboquadrina acostaensis* (Blow); a: umbilical side; b: spiral side; sample PK 58, section 2.

Figs. 13-15, 17. Benthic species characteristic for the middle Messinian, restricted marine Assemblage C; the species of Fig. 16 is from the Recent.

Fig. 13a, b. The small Uvigerina sp. A; sample MI 151, section 2.

Fig. 14. Bolivina plicatella Cushman; sample PK 52, section 2.

Fig. 15. Asterigerina planorbis d'Orbigny; sample PK 56, section 2.

Fig. 16. *Elphidium* sp. cf. *E. margaritaceum* Cushman; sample HP 88002, Salin de Gruissan (Aude, S. France).

Fig. 17. *Elphidium* sp. A; a: normally developed specimen; b: specimen with aberrant last chamber; sample MI 308, section 3.

Fig. 18. *Ammonia tepida* (Cushman), benthic foraminifer characteristic of the late Messinian 'continental' Assemblage D; a: umbilical side, b: spiral side, c: umbilical side; three specimens from Sample MI 112, Section 3.





Fig. 4. Geochemical data on the Abad Marl. Note: higher Mg, Mn, Fe, and SO₄ content for Upper Abad Marl, showing their higher dolomite content, especially in the top, and enrichment in metal-hydroxides and fine-crystalline gypsum.

The lower Subassemblage D1 (samples PM 307-Ml 135) still has a low microfossil diversity (*Cyprideis agrigentina*, *Elphidium* sp. A, *T. quinqueloba*) and contains fish remains. In the sediment manganese hydroxide is still present. Subassemblage D 2 has typical brackish to fresh-water ostracods (*Tyrrhenocythere pontica*, *Loxoconcha djaffarovi*) and is further characterized by a relatively poor, but diverse, marine foraminiferal assemblage and a high content in fine terrigenous debris and iron-hydroxides. Samples from its top contain lignite.

Reworking of the marine foraminiferal fauna is first suggested by its mixed nature (diverse planktic foraminifers, characteristic buliminids from Assemblage B and benthic species characteristic of Assemblage A), the occurrence of browncoloured and damaged individuals, the presence of *Globorotalia conomiozea* and sinistral *N. acostaensis* which are characteristic for the earliest Messinian (both in Mediterranean and in nearby marine Atlantic sections: Bossio et al., 1977; Geerlings & van de Poel, 1979; Hodell et al., 1989), and the occurrence of early Messinian reef limestone fragments in associated river conglomerates (van de Poel, 1991). The nonmarine ostracods are well preserved.

Assemblage E (samples Po 152-178; Pl. 3).

The base of this assemblage is marked by the reappearance of a rich and diverse benthic foraminifer assemblage, characterized by robust *Textularia* spp. and nodosariids, *Siphonina planoconvexa*, *Neoeponides schreibersii*, *Uvigerina longistriata*, and relatively common robust rotaliids. The abundance of characteristic lower Messinian (Assemblages A and B) taxa in this assemblage is ascribed to reworking, indicated by the presence of typical early Messinian planktic foraminifers (*Globorotalia cono-miozea*, sinistrally coiled *N. acostaensis*) and continental Assemblage D markers (ostracods, *Chara* and *Microcodium* remains). Preservation, abundance and diversity of the autochthonous planktic foraminifers is moderate. The return of glauconite and common echinoid remains further marks the base of Assemblage E.

The lower Subassemblage E1 is characterized by the abundance of *Cibicidoides dutemplei* and the relatively common occurrence of buliminids. A large part of the latter is considered reworked, but *Bolivina alata* only occurs in samples from this assemblage (PK 81 and Po 155, Section 1).

Diversity again decreases in the upper Subassemblage E2 (samples Po 134-166), where *Cibicides lobatulus* is the most abundant benthic species, and *Globigerinoides* dominates the planktic assemblage.

PLANKTIC FORAMINIFER ZONES

The following local planktic foraminifer subdivision can be compared with the Mediterranean 'standard' Zonation of Kastens et al. (1990) (Fig. 5):

Globorotalia suterae Zone — Globorotalia suterae and G. menardii occur in the lowermost samples of Sections 1 and 3, where Globorotalia conomiozea is absent. Such an assemblage is typical for the uppermost Tortonian Globorotalia suterae Subzone of the Globigerinoides obliquus extremus Zone of Glaçon et al. (1990).

Globorotalia conomiozea Zone — From the first appearance of the nominate species to the change in coiling direction of N. acostaensis from predominantly sinistral to dextral (Geerlings & van de Poel, 1979; Iaccarino, 1985; Glaçon et al., 1990).

Turborotalita quinqueloba Zone — From the coiling change of N. acostaensis up to the top of the interval in which, consistently, the nominate species is the dominant form. The term T. multiloba Zone for this interval (Colalongo et al., 1979) is not used, since the endemic T. multiloba Romeo is very rare in the investigated samples. The same has been observed in the adjacent Sorbas Basin (Geerlings, 1977). A barren interzone is recognized for the interval in which planktic foraminifers are either absent or extremely scarce.

Reworked Interzone — This interval shows an upwards increase in frequency and diversity of the planktic foraminifer fauna, which may be well preserved, but is mixed, as indicated by the presence of G. conomiozea and sinistrally coiled N. acostaensis, and is considered reworked. Reworking is further indicated by the presence of damaged shells, brown individuals and abundant fine terrigenous debris (see also under Assemblage D).

Globorotalia margaritae Zone — From an abrupt increase in frequency and diversity of planktic foraminifers, accompanied by other marine microfossils, up to the first

appearance of *Globorotalia puncticulata* (Enclosures 2-4; Fig. 3). A few, poorly preserved individuals of the nominate taxon (predominantly the small *G. margaritae primitiva* Cita) are present in most of the samples. *G. margaritae* is absent from the lowermost samples of this interval in Section 3. Although a few *Sphaeroidinellopsis* sp. have been observed the material does not allow a confirmation of the presence of the earliest Pliocene *Sphaeroidinellopsis* Acme Zone (MPL1) of the central Mediterranean (Cita, 1975; McKenzie & Sprovieri, 1990). Its presence can be demonstrated at the base of the Cuevas Formation of the adjacent Vera Basin ('Zone du Passage' of Montenat et al., 1976).

Globorotalia puncticulata Zone — From the first appearance of the nominate species up to the top of the section. This Zone contains advanced G. margaritae forms. The youngest sample (Po 160 C, Section 1), which still contains G. puncticulata, but Globorotalia crassaformis instead of G. margaritae, may represent Zone MPI 4 of Cita (1975) (Fig. 5).

Environmental interpretation and age of the events

The recognized succession of assemblages serves to interpret the evolution of some palaeoenvironmental factors (waterdepth, salinity and oxygen content), whereas the planktic foraminifer zonation allows an age assignment to the events (Figs. 5, 6).

AGE

The main planktic foraminifer events, and therewith the changes in facies, can be

Plate 3

SEM micrographs of characteristic, relatively shallow, open marine foraminifera from the Pliocene.

Figs. 1-6. Species characteristic of the early Pliocene, outer neritic Assemblage E1; 1-4: \times 65; 5-6: \times 100.

Fig. 2. Cibicidoides dutemplei (d'Orbigny); a: umbilical side; b: spiral side; sample Po 135, section 3.

Fig. 3. Bolivina alata (Seguenza); sample PK 81, section 1.

Fig. 5. The small *Globorotalia margaritae* Bolli & Bermudez forma *primitiva* Cita; a: umbilical side of sinistrally coiled specimen, b: dorsal side of dextrally coiled specimen.

- Fig. 6. Umbilical side of particularly small, dextrally coiled specimen of *Globorotalia margaritae* Bolli & Bermudez forma *primitiva* Cita; sample Po 178, Section 3.
- Figs. 7-10. Species characteristic of the middle Pliocene, inner-neritic Assemblage E 2; $7-8: \times 50$; $9-10: \times 100$.
- Fig. 7. Neoeponides schreibersii (d'Orbigny); sample Po 178, section 3.
- Fig. 8. Coarse punctate form of Cibicides lobatulus (Walker & Jacob); sample Po 160D, section 1.

Fig. 9. Globorotalia margaritae Bolli & Bermudez forma margaritae Cita; sample Po 178, section 3.

Fig. 10. *Globorotalia puncticulata* Deshayes; a: umbilical side; b: side view; c: spiral side; two specimens from Sample Po 160D, Section 1.

Fig. 1. Siphonina planoconvexa Silvestri; sample 134, section 3.

Fig. 4. Uvigerina longistriata Perconig; sample 178, section 3.





Fig. 5. Comparison of the local planktic foraminiferal zonation and events with the 'Standard Mediterranean Zonation', and their correlation with the timescale of Berggren et al. (1985, modified after Zijderveld et al., 1986 and Channell et al., 1990).

Fig. 6. Estimated depth, salinity and oxygen-content of the bottom waters for the centre of the late Tortonian-middle Pliocene Carboneras-Nijar Basin.



450 WATERDEPTH <u>о</u> 150 Mw PALEOENVIRONMENT 0 Э 200 150 SALINITY HYPERSALINE 100 50 %. BRACKISH 4 ω OXYGEN N °∑^{bw} ENV. STAGE I П Ш IV ۷ ۷

dated in terms of the timescale of Berggren et al. (1985, slightly modified in Figs. 5 and 6, left part).

The first appearance of G. conomiozea in the Mediterranean occurs within the Chron 6 Normal Zone and has an age of 6.43 Ma (Channell et al., 1990). The boundary between Subassemblages A1 and A2, which coincides with the lithologic boundary between the Azagador Sandstone and the Abad Marl, is slightly older, being situated in the upper part of the G. suterae Zone (total age ~6.90-6.43 Ma; Glaçon et al., 1990), and is estimated at 6.5 Ma.

The sinistral to dextral coiling change of *N. acostaensis* is estimated at 5.85 Ma since it approximates, according to Bossio et al. (1977), the first appearance of *Amaurolithus tricorniculatus* which falls in the lower normal interval of Chron 5 (Haq et al., 1980), and is slightly older than the first appearance of *Pulleniatina primalis*, which also takes place in the lower normal of Chron 5 at 5.8 Ma (Saito et al., 1975; van Gorsel & Troelstra, 1981; Berggren et al., 1985).

The next three Zonal boundary ages are calculated using the above ages and assuming constant sediment accumulation rates for the Abad Marl.

The age of initiation of faunal impoverishment, marked by the base of the A3 Subassemblage, which characterizes the top of the Lower Abad Marl, has been calculated at 6.10 Ma. The same age is given by Hodell et al. (1989) to a shift in ∂^{18} O in the Bou Regreg section (NW Maroc), which they correlate with the onset of diatomaceous 'Tripoli' sedimentation in the Sicilian Messinian type area.

The major change in fossil and lithologic composition which marks the base of Assemblage B and of the Upper Abad Marl, respectively, has been calculated to be at 6.0 Ma. This is close to the age calculated for the base of Sicilian Tripoli Formation by Schrader & Gersonde (1978) and Gersonde & Schrader (1984).

The record of Section 3 suggests a gradual onset of 'Tripoli' sedimentation, the Upper Abad Marl correlating with the Sicilian Tripoli Formation on basis of lithology, stratigraphic position and the coiling change of N. acostaensis in the middle of both formations (van de Poel, 1991). The 'acme' of G. bulloides, which precedes the N. acostaensis coiling change, reflects eutrophic conditions (Reiss & Hottinger, 1984; Troelstra & Kroon, 1989; Barmawidjaja et al., 1989). In Section 3 it is situated at the level where the first common diatomites have been observed.

The age of the boundary between Assemblages B and C, which coincides with the boundary between the Abad Marl and the Yesares Evaporite, is calculated at 5.6 Ma. This is close to the 5.7 Ma calculated by Gersonde & Schrader (1984) on basis of diatom correlations for the boundary between Tripoli Formation and the 'Lower' Messinian evaporites of the Mediterranean, which is commonly used in Messinian 'scenarios' (McKenzie et al., 1984; Müller & Hsü, 1987). It confirms a former stratigraphic contention of the approximate age-equivalence of the initiation of Yesares and central Mediterranean evaporite deposition, respectively (van de Poel, 1991).

The abrupt boundary between the Feos and Cuevas Formations (boundary between Assemblages D and E) is equated to the base of the Pliocene in the Mediterranean, which falls in the top part of the lower reversed interval of the Gilbert Chron, just below the Thvera Subchron and has an age of ca. 4.85 Ma (Zijderveld et al., 1986; Channell et al., 1990). As recorded in the Sphaeroidinellopsis Acme, it is contemporaneous in the Vera Basin of SE Spain and in the central Mediterranean, but needs further detailed investigation in the Carboneras-Nijar area.

Ages for facies events within the interval between the two latter datum-levels (i.e. within the Yesares and Feos Formations/Assemblages C-D) are problematical due to the lack of biostratigraphic markers. The more open-marine interval in the higher part of the Yesares Formation (Subassemblage C3) compares with a similar level near the top of the Yesares Formation of the adjacent Sorbas Basin (Montenat et al., 1980; Ott d'Estevou, 1980) and is possibly correlatable to a marine interval in the Fortuna Basin (SE Spain) for which an age of ca. 5.35 Ma has been suggested by Müller & Schrader (1989). The youngest Messinian deposits then entirely fall in the lower reversed period of the Gilbert Chron as is the case in the central Mediterranean (Channell et al., 1990). The brackish Assemblage D of the Feos Formation is characteristic of the Mediterranean 'lago mare' (Ruggieri & Sprovieri, 1976; Colalongo et al., 1978; Cita et al., 1978) and correlates with a strong glacial maximum found in the world oceans in the lower reversed period of the Gilbert Chron (van Gorsel & Troelstra, 1981; Müller & Hsü, 1987; McKenzie et al., 1988).

Globorotalia puncticulata first appears in the Mediterranean at the end of the Gilbert normal B chron at 4.13 Ma (Zijderveld et al., 1986; Rio et al., 1990). The G. puncticulata base has been found by Völk (1967) just below the top of the Cuevas Formation in the Vera Basin, but in the Carboneras area much of the Cuevas Formation has probably been eroded. Since the Molata Formation (and Subassemblage E2) contains G. puncticulata, its transgressive base is somewhat younger than this event and may coincide with the sequence boundary at 3.8 Ma of Haq et al. (1987).

Globorotalia. margaritae has its last occurrence close to the top of the Gilbert Chron at 3.5 Ma (Berggren et al., 1985; Rio et al., 1990). Our youngest sample, from the upper part of the Molata Formation, which contains no longer G. margaritae but still G. puncticulata, should have an earliest Late Pliocene age between 3.5 and 3.3 Ma (fig. 10 of Rio et al., 1990).

PALAEOENVIRONMENTS (FIG. 6)

At the end of the Tortonian the near-shore environment recorded in the main part of the Azagador Sandstone (van de Poel, 1991), was rapidly replaced by the open marine conditions indicated by the diversity of benthic and planktic foraminifera and the presence of glauconite in Assemblage A. The abundance of *Amphicoryna scalaris, Lenticulina* spp., *Cibicidoides pseudoungerianus, Planulina ariminensis, Pullenia, Gyroidina,* and *Melonis* spp., the presence of *Bigenerina nodosaria* and *Eggerella bradyi*, and the virtual absence of *Cibicidoides dutemplei* and other typical shelf-taxa, suggest an upper bathyal waterdepth of 300-400 m for Subassemblage A2 (cf. Pujos, 1976; Jorissen, 1988; van Marle, 1988).

Subassemblage A3, with its first reduction in benthic diversity, records the initiation of aberrant bottom conditions towards the end of the earliest Messinian. Its increase in importance of buliminaceans indicates increased nutrient and/or lowered oxygen levels at the sea bottom (van der Zwaan, 1982; Reiss & Hottinger, 1984; Troelstra, 1989). Yet, non-buliminacean benthic foraminifera remain present and the abundance of *Cibicidoides pseudoungerianus*, *Bulimina costata* and *Uvigerina peregrina* suggests that oxygen depletion did not reach extreme 'Mediterranean' values (van der Zwaan, 1982; Jonkers, 1984; Jorissen, 1987). The fauna compares with those of the margins of oxygen minimum zones in upwelling areas (Harman, 1964; Ingle et al., 1980; Lutze, 1986; van Marle, 1988; Hermelin & Shimmield, 1990). The observed fluctuations in relative frequencies of the buliminaceans reflect fluctuations in oxygen content of the bottom waters.

The presence of 'small deep water species' and the frequency of Bulimina costata, Planulina ariminensis, Bolivina spathulata and Cibicidoides pseudoungerianus (rather than C. bradyi (Trauth)), suggest a waterdepth of 250-350 m for this interval (Pujos, 1976; Ingle et al., 1980; Kouyoumontzakis, 1987; Jorissen, 1988; van Marle, 1988).

The dominance of buliminaceans in Assemblage B reflects the high nutrient budget in the Mediterranean during the latest early Messinian (van der Zwaan, 1982). The abundance of small-sized species also is indicative of a high nutrient supply (Lankford, 1959; Phleger & Soutar, 1973). Strong oxygen-deficiency in the lower part of the water-column is further attested to by the common preservation of lamination (below 0.3 mg/l: Harman, 1964), the high quality of preservation of the foraminiferal faunas (Phleger & Soutar, 1973), and of fish and plant remains (van de Poel, 1991), whereas the occurrence of manganese-hydroxide levels also suggests 'suboxic' conditions at the sediment-water interface (van de Poel & Klaver, 1989). *B. spathulata* and comparable forms seem to avoid extreme oxygen deficiency (less than 0.1 mg/l) (Harman, 1964; Jorissen, 1988). Consequently, extremes were not reached during Assemblage B deposition.

The presence of *Rectuvigerina cylindrica* confirms the upwelling of deep Atlantic water into the Mediterranean during the latest early Messinian (Lutze, 1986). Abundance of *B. spathulata* or comparable forms (i.e. *B. argentea* Cushman, *B. aff. rankini* Kleinpell, *B. ordinaria* Phleger & Parker) and/or the *Bulimina aculeata* plexus (*B. aculeata*, *Bulimina* sp. 1 Hermelin & Shimmield, *B. marginata-denudata*, *B. elongata*) is reported from both oxygen minimum zones in upwelling areas (Harman, 1964; Lutze, 1979; Ingle et al., 1980; Troelstra et al., 1989; Hermelin & Shimmield, 1990) and semi-enclosed marine basins (Reiss & Hottinger, 1984; Jorissen, 1987; Barmawidjaja et al., 1989). Both taxa have some tolerance to increased salinities (Reiss & Hottinger, 1984; Debenay et al., 1987).

Aberrant conditions also prevailed in the higher part of the watercolumn as indicated by a decrease in diversity of the planktic foraminifer faunas. Abundance of *G. bulloides* and *N. acostaensis* indicates high nutrient levels, whereas the abundance of *G. conomiozea* (the fossil equivalent of *G. menardii*) is suggestive of upwelling conditions (van der Zwaan, 1982; Troelstra & Kroon, 1989). These species are most frequent in the lower part of Assemblage B, while *T. quinqueloba*, globigerinoids (in particular *G. obliquus*) and *Orbulina* spp. dominate its upper part. Of these, only *T. quinqueloba* is sometimes seen to thrive particularly well in high-productive areas (pers. comm. G.J. Brummer and S.R. Troelstra). *T. quinqueloba* and the modern equivalent of *G. obliquus*, *G. ruber*, are surface-dwellers and together with *Orbulina* they are all three reputated for their tolerance to a relatively wide range of salinities (Ganssen & Troelstra, 1987; Kroon et al., 1988; Bijma et al., 1990). Müller & Hsü

(1987) have recorded a decrease in planktic ∂^{18} O in the top of the Abad Marl of the adjacent Sorbas Basin, which was interpreted as possibly reflecting a greater freshwater influence. However, the persistance of planktic foraminifers in itself excludes extreme salinity variations in the surface waters.

The composition and, at levels, abundance of the 'shallow water component' of the benthic foraminiferal fauna, indicates a well-vegetated environment with either normal marine salinity or a tendency to hyposalinity in the uppermost water levels (Lankford, 1959; Murray, 1973; Sen Gupta & Schafer, 1973; Pujos, 1976; references quoted in van der Zwaan, 1982; Zaninetti, 1982; Coppa, 1987; Debenay et al., 1987; Jorissen, 1987; Moodley, 1990; Culver, 1990).

Alltogether, the foraminiferal facies distribution of Assemblage B is in accordance with oxygen isotope data for the adjacent Sorbas Basin and basins in the central and eastern Mediterranean (van der Zwaan, 1982; Müller & Hsü, 1987), which indicates the existence of a relatively strong salinity gradient during this interval.

Subassemblage B1 still has levels with somewhat more diverse benthic and planktic foraminiferal faunas and shows fluctuations in the Fe and Mg content (Fig. 4). Levels with common *C. pseudoungerianus* and *Uvigerina* cf. *peregrina* and the general frequency of *Cassidulina* spp. suggest relatively better oxygenated conditions (van der Zwaan, 1982; Jonkers, 1984; Barmawidjaja et al., 1989). This interval records a fluctuating shift towards the consistent conditions with low-oxygen and somewhat deviating salinities reflected by Subassemblage B2. The paucity in calcareous fossils in Subassemblage B3 is probably largely the result of secondary dolomitization (see also Mg-curve of Fig. 4), which can give rise to dissolution of calcareous tests (Kelts & McKenzie, 1982). In the adjacent Sorbas Basin, where dolomitization of the uppermost Abad Marl is not evident, common, normally preserved calcareous microfossils remain present in this interval.

The disappearance of all 'deep water' indicators near the base of Assemblage B, and the concomitant appearance of a number of shallow-water species, suggest a shoaling trend in the Abad Marl (Troelstra et al., 1980). The sudden abundance of very shallow water indicators (small specimens of *Elphidium* spp., *Ammonia*, miliolids, 'epiphytes', shallow water ostracods) in the laminites at the base of Assemblage B is partially due to displacement by turbidity currents: large, robust specimens of the same taxa occur in samples from turbidite beds of the same age. Floating plant material, such as the large seagrass fragment found in the Upper Abad Marl of Section 1 (van de Poel, 1991: Pl. 2c), probably further formed an important transport vehicle for epiphytes (van der Zwaan, 1982; Jorissen, 1987; Troelstra, 1989, p. 159). Bolivina plicatella (which may also be epiphytic: van der Zwaan, 1982), Hopkinsina banoniensis and Bulimina elongata also could have been transported since they are commonly reported from modern, shallow, often slightly hyposaline waters (Murray, 1973; Pujos, 1976; Haake, 1977; references in van der Zwaan, 1982; Zaninetti, 1982; Lutze, 1986; Coppa, 1987; Debenay et al., 1987; Moodley, 1990; Culver, 1990). Waterdepth estimates have to be made on the remaining benthic elements. The presence of U. peregrina, C. pseudoungerianus, and some P. ariminensis and 'small deep water species' in the base of this zone suggests waterdepths of at least 150 m for this interval (Pujos, 1976; Jorissen, 1988; van Marle, 1988). Hanzawaia boueana, Florilus boueanum and Valvulineria bradyana may well be autochthonous, since they are relatively common and have been reported from modern environments dominated by buliminaceans. They are reported as common in waterdepths up to 200 m and sometimes more (Hanzawaia boueana) (Pujos, 1976; Ingle et al., 1980; van der Zwaan, 1982; Jorissen, 1988). Abundance of Bolivina spathulata, the most common species of Assemblage B, is characteristic of the shelf edge and upper slope (Murray, 1973; Pujos, 1976; Jorissen, 1988). Comparison of the uvigerinid species of Assemblage B with those of the modern central-eastern Atlantic, where Hopkinsina bononiensis has a lower depth limit of 150 m and Rectuvigerina cylindrica an upper depth limit of 150 m and its maximum between 250 and 500 m (Lutze, 1986), indicates a waterdepth below 150 m for the entire Assemblage B. All together, 150 to 250 m waterdepth seems a reasonable conclusion. This depth fits the geometry of reconstructed topographic differences between Upper Abad Marl and contemporaneous marginal reef deposits (such as those at Polopos: Fig. 1; Troelstra et al., 1980; van de Poel et al., 1984; van de Poel, 1991).

Assemblage C, recognized in interbedded marks of the Yesares and basal Feos Formation, is generally poor in faunas, whereby completely barren intervals are probably the combined result of an extreme original environment and secondary dolomitization (van de Poel, 1991). The strongly reduced diversity in Assemblage C, and the fact that *Elphidium* and *Cyprideis* (two genera known to thrive under hyposaline and hypersaline conditions: Truc, 1980; de Deckker et al., 1988) are relatively common, further indicate that the open marine connection had become considerably obstructed. The association of Assemblage C with gypsum suggests continuously hypersaline conditions, but it is peculiar that miliolids and Ammonia beccarii are relatively rare as they are known to thrive in shallow hypersaline environments, commonly in company of Elphidium and Cyprideis (Murray, 1973; Zaninetti, 1982; Debenay et al., 1987; personal observations on samples from the natural salt works of Gruissan, southern France). This can be explained by assuming a relatively deep water environment for the main part of Assemblage C. Subassemblage C2 contains a benthic foraminiferal fauna (common small Ammonia, accompanied by diverse small epiphytes, some miliolids, *Elphidium*, *Bolivina plicatella* and *Fursenkoina*) which compares with faunas described from modern shallow lagoonal environments (Debenay et al., 1987; Culver, 1990).

The relatively constant open marine signal (*T. quinqueloba*, scattered marine benthic foraminifera, sponge spicules and bryozoan remains) in Assemblage C, can often be linked to the relative abundance of fine terrigenous clastics, and hence to reworking. The richer, internally consistent fossil assemblages of Subassemblage C3, which sometimes include abundant, well-preserved remains of marine sponges, are considered to be the result of temporary more open-marine conditions. The reconstructed topographic height difference between the deposits in which Assemblage C occurs and contemporaneous oolite-rich beds from the basin margin (exposed near Polopos, Fig. 2), indicates, at least temporary, considerable waterdepths, comparable to those of Assemblage B, in the centre of the basin (van de Poel, 1991, fig. 9).

Oxygen-content of the bottom waters was low as attested by the abundance of lamination. *Elphidium*, *Cyprideis* and *Ammonia* are taxa that can survive low oxygen levels that are common in lagoons or estuaria, where they proliferate (Lutze, 1965; Moodley, 1990; personal observations in the 'Salin de Gruissan').

Assemblage C attests to the transition from the open marine environment of the early Messinian to the late Messinian 'continental' conditions recorded in Assemblage D. The most common microfossils of Subassemblage D1 (*Cyprideis* and *Ammonia tepida*) can again be interpreted as reflecting either a brackish or hypersaline environment. A relatively high salinity level may have been maintained by the reworking of evaporites from the middle Messinian Yesares Formation (van de Poel, 1991). The presence of typical brackish 'lago mare' molluscs and of *Chara* and *Microcodium*, on the other hand, suggest an increased influx of fresh water in the basin in comparison with the underlying interval. Assemblage D1 may well have originated under rapidly fluctuating, 'schizohaline' conditions (Colalongo et al., 1978). Sedimentological features and reconstruction of the basin topography suggest that several tens of metres waterdepth were still commonly attained during this time-interval (Roep & van Harten, 1979; van de Poel, 1991).

The presence of low-salinity ostracod species and lignite fragments in Assemblage D2 record a further freshening and shallowing of the basin towards the end of the Messinian, which is corroborated by the sedimentary facies (Roep & van Harten, 1979; van de Poel, 1991). The attenuation of lamination, and the presence of limonite, burrowing and abundant mollusc remains indicate better oxygenation of the basin at the same time.

A sudden return to open marine conditions is marked by the abrupt increase in microfossils and by the reappearance of echinoids and glauconite, at the base of Assemblage E. The relative frequency of planktic foraminifers and the dominance of *Cibicidoides dutemplei* indicate outer shelf waterdepths for Subassemblage E1 (Kafescioglu, 1975; van Marle, 1988). Depth may have been somewhat greater at the location of section 1, where *Cibicidoides pseudoungerianus* and *Bolivina alata* are common.

The local angular unconformity at the base of the Molata Formation and the poor development of the lowest Pliocene in the Carboneras area, attest to a period of uplift and erosion (van de Poel et al., 1984; van de Poel, 1991; Figs. 5, 6), after which the shallow marine conditions of middle Pliocene Subassemblage E2, in which *Cibicides lobatulus* and *Elphidium crispum* dominate, were installed.

Conclusion and discussion

Five distinct biostratigraphic units of the Carboneras-Nijar Basin represent the latest Tortonian to early Pliocene succession of relatively deep, open marine (I), relatively shallow marine, eutrophic (II), relatively shallow to shallow, very restricted marine (III), brackish, continental (IV), and renewed open marine, but shallow (V) environmental stages (Fig. 6). The foraminiferal biofacies of Assemblage B indicates that the basin still had good connections with the open ocean during the latest early to earliest middle Messinian Stage II. At the same time, however, the first indications of enclosure of the basin (enlarged fresh-water influence in the superficial waters and development of a salinity gradient) are found. These mark the onset of a fluctuating shift to complete dominance of continental over marine conditions, characterizing late Messinian Stage IV. This development can be compared with central Mediterranean and nearby NW Atlantic sections (Fig. 1).

The rapid increase in waterdepth at the end of the Tortonian (Fig. 6), can be observed in many sections inside the Mediterranean (van der Zwaan, 1982; Glaçon et al., 1990) and outside in the Atlantic Guadalquivir (Glaçon et al., 1990) and Rharb Basins (Bossio et al., 1977; personal observations).

The earliest Messinian, deep open marine assemblage of Subassemblage A2, compares with Atlantic assemblages of the same age from the Guadalquivir Basin (Verdenius, 1970; Berggren & Haq, 1976; Glaçon et al., 1990, fig. 3) and the Rharb Basin (unpublished data), and with northern Italy (Colalongo et al., 1979) and offshore Lybia (van Hinte et al., 1980) within the Mediterranean. The Central Sicilian Basin is characterized by the total absence of benthos (Colalongo et al., 1979; van der Zwaan, 1982). Apparently, there was an open connection with the Atlantic, but normal marine conditions existed in the Mediterranean only in the upper few hundred metres of the water column, whereas anoxity occurred in its deeper parts. Planktic foraminiferal assemblages already show some marked differences with the Atlantic, which have relatively common *Sphaeroidinellopsis* spp. and globoquadrinids and relatively rare G. conomiozea (Bizon et al., 1972; Wernli, 1977; personal observations), suggesting a separation of the water masses.

The typical buliminid-rich Assemblage B is characteristic for all Mediterranean sections in the interval encompassing the *N. acostaensis* coiling change (Colalongo et al., 1979; van Hinte et al., 1980; Orszag-Sperber et al., 1980; van der Zwaan, 1982). At the same time diverse benthic and planktic assemblages persisted in the Atlantic, where the first primitive *G. margaritae* appear (Wernli, 1977; personal observations). The only evidence that the Atlantic had a better connection with SE Spain than with the central Mediterranean is the scarcity of the endemic *T. multiloba* in our area.

The first appearance of *G. margaritae* s.s. outside the Mediterranean approximately coincides with the onset of Mediterranean evaporite deposition (Bossio et al., 1977; Fig. 5). Above this level diverse foraminiferal assemblages persist in the Rharb and Guadalquivir basins (Perconig, 1966; Verdenius, 1970; Berggren & Haq, 1976). The Carboneras area had only scarce open marine influence during the evaporite deposition. From Italy also a few more open-marine intercalations have been described from levels within or at the top of the lower evaporites (Selli, 1973; Sturani, 1978; Vai & Ricci Lucchi, 1978).

The Messinian overlying the evaporites in the basins of SE Spain contains a characteristic biofacies (Sorbas Basin: Roep & van Harten, 1979; Vera Basin: Geerlings et al., 1980 a, b; Nijar Basin: our Assemblage D) comparable to the typical 'lago mare' assemblages described from Italy (Ruggieri & Sprovieri, 1976; Colalongo et al., 1978). In the deposits directly overlying the evaporites in the central part of the Carboneras-Nijar and Sorbas basins of SE Spain (our Subassemblage D 1), marine fossils are either absent or a few specimens are found of which the autochthonous nature is questionable (Ott d'Estevou, 1980, p. 80/81; this paper). The relative abundance of planktic foraminifers in the youngest Messinian deposits of the Vera and Nijar basins (Montenat et al., 1976; de la Chapelle, 1987) has been demonstrated to be due to reworking (Geerlings et al., 1980a, b; this paper). The absence of marine late

Messinian in the deeper parts of the basins, is an important argument to correlate marine intercalations near the top of the marginal deposits of the Agua Amarga, Sorbas and Nijar basins (Esteban & Giner, 1980; Ott d'Estevou, 1980; van de Poel, 1991) with marine levels in the 'middle' Messinian Yesares Formation, rather than to consider them late Messinian in age (Montenat et al., 1980).

The basins of southeastern Spain abruptly returned to open marine conditions in the early Pliocene, as did the rest of the Mediterranean (e.g. Cita, 1973; Casati et al., 1978).

Appendix: Explanatory note on the microfossil taxa

In the distribution charts (Enclosures 2-4), individual taxa are plotted in larger groups. The following explanation can be given on their composition. Biostratigraphically important taxa are illustrated in Pls 1-3 and their ranges are given in Fig. 3.

Planktic foraminifers

Globorotaliids are presented as keeled and unkeeled forms in Enclosures 2-4. The keeled forms mainly belong to the *Globorotalia miotumida* Jenkins group (sensu Sierro, 1985) with common *G. conomiozea* Kennett (Pl. 1, fig. 13). A few small advanced forms of the *G. menardii* d'Orbigny plexus (cf. *G. menardii* forms 4 and 5 of Tjalsma, 1971 and Zachariasse, 1975) occur in the lowermost samples, whereas *G. margaritae* Bolli & Bermudez (Pl. 3, figs. 5, 6 and 9) and *G. crassaformis* Galloway & Wissler are present in the upper part of the section (Fig. 3).

Unkeeled globorotaliids are G. scitula Brady, the ventrally high G. suterae Catalano & Sprovieri, and G. puncticulata Deshayes (Pl. 3, fig. 10).

The neogloboquadrinids are N. acostaensis (Blow) (Pl. 2, fig. 12) with N. humerosa (Takayanagi & Saito) as a common companion in the Lower Abad Marl.

Globigerinita spp. commonly occur in samples from the Abad Marl, but have been taken together in Enclosures 2-4 and Fig. 3 with the far more dominant *Turborotalita quinqueloba* (Natland) (Pl. 2, fig. 11).

The Globigerina spp. mainly are G. bulloides d'Orbigny (s.l.), G. obesa Bolli and Globigerinella aequilateralis (Brady), but also include G. decoraperta Takayanagy & Saito and G. nepenthes Todd. An acme of the first group is observed in several samples from the lower part of the Upper Abad Marl, where G. bulloides often has a bulla.

The Globigerinoides spp. of the Abad Marl are G. obliquus Bolli and G. obliquus extremus Bolli & Bermudez with less common G. trilobus Reuss (s.l.). In the Pliocene formations both groups are more evenly distributed. Orbulina shows a wide range of form variation in the Upper Abad Marl.

Benthic foraminifers

The category 'agglutinants' contains finely agglutinated species (predominantly Spiroplectammina carinata (d'Orbigny), Martinottiella communis (d'Orbigny), Eggerella

bradyi (Cushman) (Pl. 1, fig. 1), and robust, coarsely agglutinated Textularia spp. (Fig. 3).

Nodosariids stands for taxa belonging to the superfamily Nodosariacea of Loeblich & Tappan (1964), excluding *Lenticulina* spp. Fragile forms, with common *Amphicoryna scalaris* (Batsch) and *Dentalina* spp., or robust, heavily costate nodosariids occur in stratigraphically different levels (Fig. 3).

Lenticulina spp. Large, robust types are restricted to the upper part of the section.

The category 'small deep water taxa' consists of Gyroidina neosoldanii Brotzen, Melonis spp. (Pl. 1, fig. 2), Pullenia bulloides (d'Orbigny), P. quinqueloba (Reuss) (Pl. 1, fig. 3) and Sphaeroidina bulloides d'Orbigny.

Cassidulina spp. stands for C. laevigata d'Orbigny, C. subglobosa Brady and C. crassa d'Orbigny (in descending order of abundance). Besides, few C. oblonga Reuss have been found.

Representatives of the genus *Cibicidoides* generally occur either as *C. pseudoungerianus* (Cushman) (Pl. 1, fig. 9), or as *C. dutemplei* (d'Orbigny) (Pl. 3, fig. 2) (Fig. 3). In Po 153 and PK 81 of Section 1 both types are common. Intergradation, as earlier suggested by van der Zwaan (1982), is here observed.

As 'epiphytes' have been counted: the robust *Cibicides lobatulus* (Walker & Jacob) (Pl. 3, fig. 8) and the smaller taxa *Hanzawaia boueana* (d'Orbigny) (Pl. 2, fig. 3), *Asterigerina planorbis* d'Orbigny (Pl. 2, fig. 15) and *Rosalina globularis* d'Orbigny. The few miliolids (mainly *Quinqueloculina* sp.) and *Cancris auriculus* (Fichtel & Moll) and *Valvulineria bradyana* Brotzen, which show the same distributional pattern as the 'small epiphytes' in the Upper Abad Marl, have been included.

The Uvigerina flintii Cushman group comprises the large, inflated uvigerinids with fine striation and a glossy appearance. Those from the lower part of the section are U. striatissima Perconig (Pl. 1, fig. 5), whereas those of the Pliocene pertain to U. longistriata Perconig (Pl. 3, fig. 4).

Uvigerina peregrina includes completely costate forms (Pl. 1, fig. 11) and forms which lack costae on the last chamber (Pl. 1, fig. 12 a, b). The latter may pertain to U. peregrina Cushman f. dirupta Todd, U. hispidocostata Cushman & Todd (cf. Poore & Stone, 1981) or still another variety of the U. peregrina plexus (cf. Uvigerina sp. 221 of Lutze, 1986). In Assemblage B from the Upper Abad Marl small specimens and forms with poorly developed costae are encountered (Pl. 2, 1a and b), which are recorded as Uvigerina cf. peregrina in Enclosures 2-4. Forms with poorly developed costae have also been found on shallow levels of the Peru-Chili Trench (Uvigerina peregrina forma A of Ingle et al., 1980).

Bulimina aculeata d'Orbigny contains both, the more typical form (Pl. 2, fig. 2) and B. aculeata d'Orbigny f. minima Tedeschi & Zanmatti (Pl. 1, fig. 8).

Bulimina elongata d'Orbigny (Pl. 2, fig. 7) shows intergradation with B. aculeata (van der Zwaan, 1982) and it is here suggested that it represents an ecophenotypic variant. It may be characteristic for the shallow, slightly hyposaline waters from which it is consistently reported (Murray, 1973; Pujos, 1976; Haake, 1977; Moodley, 1990)

The Bolivina spathulata group consists of the short, robust, B. dilatata Reuss (Pl. 1, fig. 7) and, less common, B. subreticulata Parr, as well as the more elongate and, especially, thinner, B. spathulata (Williamson) (Pl. 2, fig. 9) and the short, thin, B. dentellata Tavani (Pl. 2, fig. 10).

Elphidium spp. contains the small species *E. fichtellianum* (d'Orbigny) (Pl. 1, fig. 4), *E. aculeatum* (d'Orbigny) (Pl. 2, fig. 4) and *Elphidium* sp. A (Pl. 2, fig. 17), as well as the robust *E. crispum* (Linnaeus). *Elphidium* sp. A resembles a Recent *Elphidium* (Pl. 2, fig. 16) which is common in pre-concentration basins of natural salt works of the Mediterranean coast of southern France (Zaninetti, 1982; personal observations in the 'Salin de Gruissan', near Narbonne). The latter has been desribed as *E. cf. alvarezianum* d'Orbigny by Zaninetti (1982). It should be remarked that similar morphotypes have been described as *E. margaritaceum* Cushman, *E. articulatum* d'Orbigny and *Cribrononion* cf. *alvarezianum* from a coastal section of the Adriatic and diverse hyposaline lagoons and estuaries (Lutze, 1965; Murray, 1973; Jorissen, 1988).

Ammonia spp. stands for Ammonia beccarii (Linnaeus) and A. tepida Cushman (Pl. 2, fig. 18).

Ostracoda

Two groups have been recognized: the genus *Cyprideis* and a group 'Other'. Within the latter, shallow marine *Aurila* sp. are characteristic for turbiditic levels of the Upper Abad Marl, whereas the late Messinian brackish 'lago mare' forms *Loxoconcha djaffarovi* Schneider and *Tyrrhenocythere pontica* Liventhal (Ruggieri & Sprovieri, 1976; Carbonnel, in Montenat et al., 1976; Roep & van Harten, 1979), are present at the top of the Feos Formation.

Algae

'Algae' stands for calcite fragments that are the product of the continental bacterium *Microcodium*, and for complete or fragmented oogonia of the fresh- to brackish water plant *Chara* sp.

Other

Additional fossil elements of the washed residues are fragments of calcareous macrofossils, remains of siliceous organisms and of fish. The pink, thin-shelled gastropods and bivalves from the Feos Formation are remains of typical 'lago-mare' molluscs (Ruggieri & Sprovieri, 1976; Colalongo et al., 1978). 'Micromolluscs' with Paratethyan affinity have been earlier reported from the top of the Messinian of the adjacent Sorbas Basin (Iaccarino et al., 1975; Archambault-Guezou, 1976; Ott d'Estevou, 1980).

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